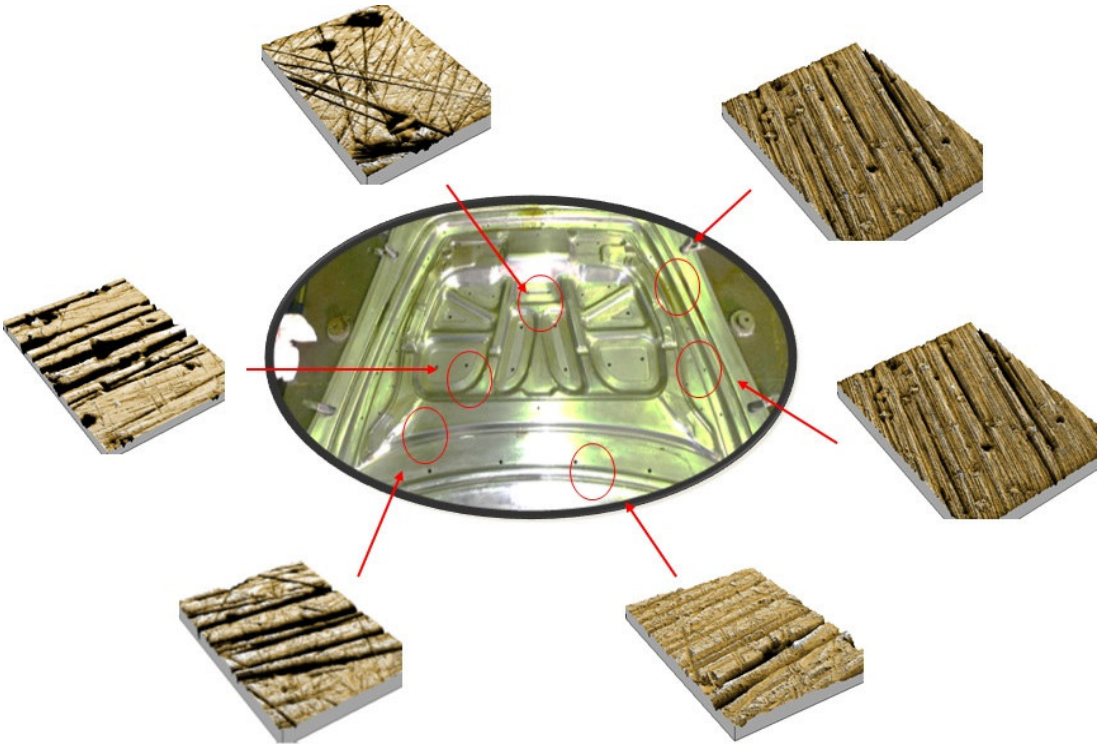
OptiDies – Optimum Die Surfaces for Cold Working Dies



Project within Sustainable Production Technology

Authors: Kenneth Kjellsson Volvo Personvagnar, Daniel Wiklund, Swerea IVF, Elisabeth Sagström, Swerea IVF, Johan Berglund, Swerea IVF, Magnus Liljengren, IUC Olofström och Mikael Kjellberg, IUC Olofström

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Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

1. Executive summary

Increased use of formed components made of advanced high-strength steels (AHSS) is a key element to lower the weight of vehicles, which is a pre-requisite to reach the goals of FFI Sustainable Production Technology to significantly reduce the emissions from fossil CO_2 and other types of emissions from secure road vehicles and machinery by creating possibilities for manufacturing of innovative sustainable and secure products.

However, when forming AHSS automotive sheet wear of tools and dies will increase, which in turn generate increases in production costs, and also reductions of productivity if no actions are taken. OptiDies, a multi-disciplinary approach, has developed new important generic knowledge which will, when implemented in industry, reduce production costs and increase productivity when forming AHSS automotive sheet.

OptiDies has created new, in-depth understanding of the prevailing complex tribo-systems when forming AHSS. Skills involved are tribology, sheet and tool steel, die manufacturing methods, numerical analysis and cost modelling.

Project realization

OptiDies has been divided in to three main work packages:

- Functional die surfaces in automotive sheet forming.
- Functional tool surfaces in automotive sheet trimming.
- Prediction of tool/die economy.

The work was carried out with use of the following approach:

- Mapping of industrial state-of-practice.
- Formulating hypothesis.
- Semi-industrial tests to test and verify the hypothesis.
- Analyses and conclusions based on the chain industrial state-of-practice-hypothesis and testing.

At all stages, the common knowledge and experience of the project members were used. All work packages have generated practical results and industrial guidelines, as well as an improved understanding of the complex tribo-systems when stamping automotive sheet.

Functional die surfaces when stamping sheet

The objective was to develop strategies to characterize the functional die surface topographies, to model the active tribo-system pertaining to predict friction and wear. Furthermore, the work package activities aimed to optimize the die surface properties when manufactured.

Functional tool surfaces when trimming automotive sheet

The objective was to develop recommendations for robust trimming processes by investigating problem areas in industrial trimming tools. Based on the results were the trimming tool surfaces optimized.

Prediction of tool economy

The objective was to reduce the cost of forming and cutting tools by development of methodologies to assess how tool material selection, and choice of active die/tool surface treatment, influence investment and maintenance costs of tools and dies.

Results and effects

Results from OptiDies are:

- Improved tools concepts which increase the possibilities to effectively form components made of AHSS sheet.
- Industrial guidelines for the choice of tool/die steel in combination with a generated functional surface on such forming and trimming tools
- Tailor-made die surface to improve its forming capability.
- Bespoke functional surfaces on cutting edges, as well as guidelines for cutting angles when trimming sheet.
- A numerical model to predict the total cost throughout die/tool life-cycle.
- A strengthened competence network for stamping dies; with members from academia, research institutes and industry.

Industrial benefits based on the results from OptiDies are:

- 20 % reduced cost and lead time in die/tool manufacturing.
- 20 % increased productivity due to reduced downtime and lower maintenance costs.
- Improved tools concepts which offer possibilities to enhance production of car body parts made of AHSS automotive sheet.

Dissemination

Knowledge from OptiDies has been distributed into academic as-well-as into industrial networks. The project has directly contributed to a licentiate thesis and, indirectly, to a doctoral dissertation. The results have been presented in two scientific journal articles,

four papers at international conferences, four presentations at national seminars and two industrial networks.

2. Background

Demands on lower car/cab weight pertaining to lower emissions, in combination with increased requirements on driver/passenger security have directed automotive manufacturers into use of steel having higher and higher strength. These grades are known as Advanced High Strength Steel (AHSS) which can be divided into sub-groups such as High Strength Steel (HSS), Extra High Strength Steel (EHSS) and Ultra High Strength Steels (UHSS). Today, use of AHSS steel in cab and body components is constantly increasing. Forming of AHSS sheet without additional lubrication increases both abrasive and adhesive wear of the die surfaces to unacceptable levels, which in turn requires dramatic improvements of tool concepts.

Tool concepts include choice of tool materials, heat treatment, die surface texturing and coating. Besides these choices there are requirements when machining a die/tool. These challenges have since years resulted in research activities at academia and in industry. However, different aspects on the complex die/tool systems have usually been studied in separate projects. Thereby the best solution for a tribo-system governing a given sheet forming operation has seldom been found. OptiDies pertain to find optimum solutions via use of an interdisciplinary approach with many different skills.

Today's recommendations for tool manufacturing cover the steel sheet grades available on the market, and also grades to be available in the near future. Use of AHSS will grow to meet future increased demands on lightweight car/cab structures and also their safety. These requirements result in continuous development in tooling concepts and die/tool manufacturing methods in combination with guidelines focusing on the tribo-system to fulfil the requirements of the 2015 sustainable stamping workshop.

3. Objective

Increased use of high-strength sheet steel in vehicles is a prerequisite to fulfil the FFI sustainable production technology targets of reduced fossil CO_2 emissions. Use of AHSS enables car/cab weight reductions in combination with increases in vehicles safety. The challenge of designing dies for forming AHSS sheet without increased tool wear requires a cross-functional research approach.

The objective of OptiDies has been to create an in-depth understanding of the complete tribo-system when forming and trimming AHSS automotive sheet by use of

interdisciplinary approaches. Competencies in tribo-systems, sheet and tool steel, new die/tool manufacturing methods, numerical analysis and cost models have been required.

4. Project realization

The research work in OptiDies project has been divided in to three work packages:

- Functional die surfaces in automotive sheet forming.
- Functional tool surfaces in automotive sheet trimming.
- Prediction of tool/die economy.

Figure 1 illustrates the structures of the project with the three work packages.

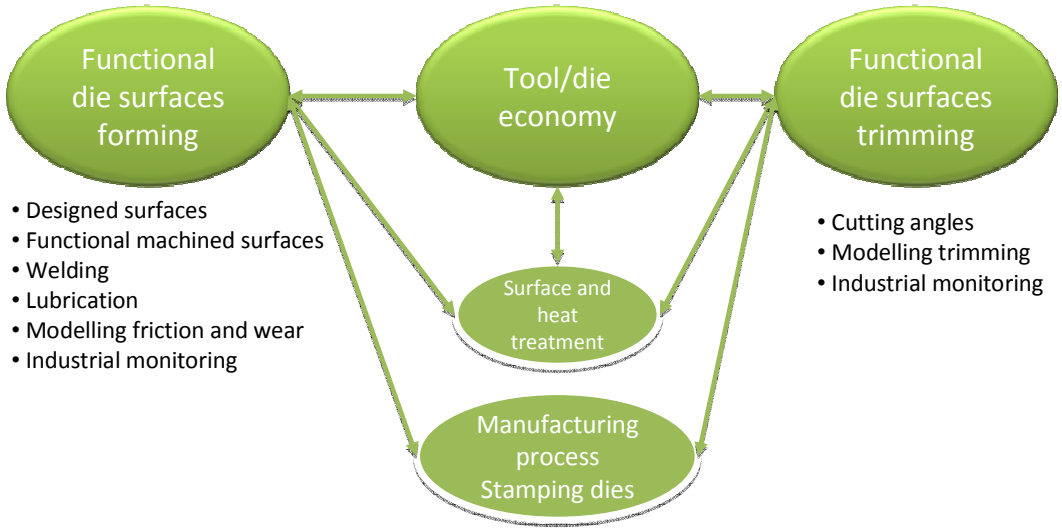

Figure 1. Influencing factors of the complete tribo-system for trimming and forming dies for sheet metal forming

The methodology used in the research work has been

1. To establish the industrial state-of-practice
2. Formulating the hypothesis
3. Semi-industrial tests to test and verify the hypotheses
4. Analysis and conclusions based on the results from the entire chain industrial of state-of-practice, hypotheses and tests.

The knowledge and experience of the project participants has helped in all aspects to realize the project.

At the start of the project were six of the participating companies forming and trimming sheet steel in their production processes (VCC, Volvo Truck, Saab, Scania, SKF and Finnveden). Differences in volume scenarios, levels of complexity and sheet steel grades used were significant between these companies.

4.2 Functional die surfaces in sheet forming

The objectives of the work package were to:

- Develop strategies and methods to characterize functional surface topographies.
- Model the tribo-system to predict friction and wear.
- Optimize the tribo-function of die surfaces already during die manufacturing.

Robust and functional surface topography parameters

The study was carried out pertaining to identify robust and functional surface topographical parameters for forming tools, and measurement strategies/methods of these surfaces. Via identification of which die surface areas are governing the tool wear, how to describe and measure these, cost and lead times for die manufacturing and maintenance can be reduced.

The study was conducted in three parts, an industrial survey of production tools and two semi-industrial tests. Robust filtering methods and parameters were identified by pooling the results from the three sub-studies.

Tribo-systems acting on die surfaces

The objective of the work package was to create a better understanding of the overall tribo-system for AHSS sheet forming, and to increase the ability to predict friction and wear. This was partly carried out as collaboration between the projects OptiDies and SimuParts. SimuParts was funded by the Swedish Foundation for Strategic Research within ProViking program, 2009-2012.
In SimuParts was the tribo-system modelled in terms of friction. The result is a model which takes into account the roughness of sheet and die surfaces and their texture directions, the sheet material hardness, the viscosity of lubricants and process parameters such as sliding speed and pressure. The model has been implemented in commercial FE software (LS-Dyna) as a user module.

Work to predict the die wear was initiated within OptiDies. It intended to predict the wear risk by use of FE simulation.

Optimization of the forming die surfaces

- *Functional milled surfaces*
  the study investigates the influence of different milling strategies in die manufacturing on friction when stamping AHSS. How to create die surfaces whose properties are similar to the tribo-properties of polished die surfaces. If tools with functionally working surfaces can be created already during machining die manufacturing lead-times can be cut, for example by reducing the need of manual polishing.
- *Welding of milled surfaces*
  the objective of this study was to investigate whether surface topography changes occur when milling a new surface on a weld repaired steel. Welding is frequently used in both manufacturing of new of tools and during tool maintenance. In tool manufacturing is welding commonly used to adjust clearance and tool geometries. Maintenance welding is used to repair defects which have occurred on tools, or to adjust geometry. The tool steel and weld metal must have properties suitable for subsequent operations such as machining, heat treatment and surface engineering (Nitriding, coatings etc.).
- *Maximum defect sizes on active die surfaces*
  this study was carried out to evaluate whether scratches which occur during the die manufacturing (e.g., by grinding or milling) have the same effect as pits from graphite nodules in cast iron when the active die surface has a controlled roughness.
- *Laser Hardening*
  laser surface hardening and induction surface hardening are common methods in die manufacturing/maintenance. Laser hardening was used to examine the possibilities to reduce differences in die surface topography which inevitably occur during the phase transformation from austenite to martensite thanks to less depth-of-hardening on the die surface during tool maintenance. Subsequent manual polishing is thereby be reduced.
- *Nitriding*
  the study has increased the understanding of the influence of the compound zone and the white layer properties which are generated when nitriding nodular cast iron. Focus was to investigate whether nodular pits show a geometry change after nitriding.

4.2 Functional die surfaces on trimming tools

Pertaining to identify and map problem areas on trimming tool surfaces, such as ones generated by the chosen machining strategy, type of cutting tool used when machining, variations in production, achieved surface topographies in combination with trimming clearance and geometry an industrial-state-of-the-art of cutting edges at the end-users was established. A selection of trimming dies, made of different steel grades, both well-functioning tools and tools with frequent maintenance intervals have been scrutinized.

Standardized procedures for cutting edge measurement and analysis had to be developed to describe the cutting edge geometries.

From the results of the state-of-practice, an empiric test matrix for evaluation of cutting edge manufacturing strategies was established as well as a test matrix for study of semi-industrial sheet trimming.

The different strategies of production of cutting edges with robust performance were analysed and improved before manufacturing of new cutting edges at Sandvik Tooling R & D, D & M.
To secure a reliable cutting edge manufacturing method with high degree of reproducibility the prepared surfaces were measured and analysed with use of high resolution laboratory techniques.
To ensure improved performance and to contribute to the understanding of the tribo-system in the trimming process of automotive sheet, test matrices based on a combination of the state-of-practice and results from manufacturing strategies were created.
Industrial guidelines for the trimming process were developed from the analyses of the tests.

4.3 Prediction of tool economy

One objective of OptiDies has been to reduce the cost of forming and trimming dies by developing methods to predict the total lifetime tool cost for a tooling concept and its influence on the price per part, including maintenance costs.
Previous VINNOVA-funded research projects such as *Tool Comp*, *Total responsibility for the tooling function* and *Itremain* have worked with calculating models to be used early in the concept phase, visualize how tolerance and complexity of a sheet metal component affects the investment cost of the die.
In OptiDies the economy model has been developed to include the influence of tool material and surface concept in the active of the tool and its effect on investment and maintenance cost.
The OptiDies cost model has been developed in two versions, one for progressive tools and another for large cast tools. The model for progressive tools is mainly aimed for companies, probably subcontractors, manufacturing smaller components. The model for large cast tools is targeted at automotive manufacturers with large press lines and their subcontractors.

5. Results

5.1 Delivery to FFI-goals

The main objective of OptiDies was to develop methods for design of the tribo-systems in automotive sheet forming and trimming pertaining to minimize die surface wear to

enable use of AHSS without increased die manufacturing and maintenance costs. The disciplines involved are: tribo-systems, sheet steel and tool steel properties, new methods of die/tool manufacturing, numerical analysis and cost modelling.

According to the FFI Sustainable Production Technology overall goals has OptiDies addressed as follow.

- Contribute to a continued competitive automotive industry in Sweden
    - The results have contributed to strengthening the competitiveness of the Swedish automotive industry and facilitated the implementation of AHSS, which contributes to the reduction of CO_2 and other emissions and improved passive passenger safety.
    - The project has reduced the cost and lead time for tool development by designing and establishing improved tool surfaces when forming AHSS.
    - Elimination of operations such as manual polishing simplifies the production chain for tool manufacturing and reduces cost and lead time.
    - Cost Models for calculation of the total tool cost throughout the entire tool life for automotive companies and their sub-suppliers have been produced.
- Implement industrially relevant developed measures
    - The project has developed improved guidelines for the preparation and characterization of surfaces on forming tools.
    - The project has developed guidelines for improved cutting angles, cutting edge geometries and surfaces of trimming tools.
- Contribute to developing industrial technology and skills
    - New manufacturing methods for functional surfaces of forming and trimming dies have been developed.
    - Streamlining the manufacturing chain for tool making by eliminating manufacturing steps reduces cost and lead time.
    - A proposal of a numerical model to predict problem areas in the forming tool surfaces have been developed, both for traditional and tailor-made functional surfaces.
    - Enhanced knowledge of how friction and wear mechanisms in tools influence the manufactured component tolerances.
- Contribute to the production improvements made at participating companies / Work to ensure that new knowledge are developed and implemented, and that existing knowledge is implemented in industrial applications
    - During regular meetings within the project group have the achieved results been presented and discussed to be implemented via standards or changes in operation at the participating companies.
- Strengthen collaboration between the automotive industry and government agencies, universities and research institutes
    - The achieved results in OptiDies are of great importance for academic institutions and for the industry and have greatly increased the knowledge regarding this topic.

- Three graduate students have worked on the project
  Johan Berglund, PhD Chalmers 2011
  Per Jonsson, Licentiate dissertation Chalmers 2010
  Magnus Liljengren, PhD student.

6. Dissemination and publications

6.1 Knowledge and results dissemination

For each new car model being developed the automotive manufacturer needs to invest somewhere between 75 and 100 million euros in a new set of production dies for body car components. The total manufacturing time for the new sets of dies is typically around nine months. Because of the fact that the forming die tools both represent a significant part of the investment cost for a new car and is a limiting factor in how fast the production of a new car model can be started, automotive manufacturers have a strong focus on bringing in new technologies and new ways of working within the area.

In the manufacturing process of sheet forming dies for the automotive industry, there is always a chain of suppliers involved. Figure 2 below shows a simplified example of how a chain of suppliers might look like.

Figure 2. Example of a supply chain that is active in the manufacture of sheet forming tools.

The desired cost and lead-time effect in manufacturing of forming and cutting dies creates a curiosity of knowledge from the die suppliers to take part of the results from OptiDies. It is of paramount importance to disseminate various results and knowledge gained from OptiDies to key suppliers involved as well as not involved in the project. Knowledge and its dissemination of results is facilitated by the fact that OptiDies can use the knowledge platform www.verktygsframtagning.se, which has been developed in previous research projects “MERA Tools”, “Tool Comp” and “Tooling Solutions”. Parallel to OptiDies several research and business partners have participated in two additional projects with main focus on the forming dies; SimuParts and FUNIF. SimuParts, funded by SSF within the program ProViking, has complemented OptiDies through an emphasis on numerical simulation (FEM), one of the focuses has been on sheet steel and die surfaces and it’s reaction on friction and springback. FUNIF, financed by VINNOVA under the EUREKA umbrella ProFactory, has worked with the

production, processing and tribological function of new types of nodular cast iron for sheet metal forming tools for the automotive industry. The interaction between the projects has been very supporting in order to reach a higher level on the results from the projects since synergies have existed between the three different projects.

6.2 Publications

Within the project the following publications have been delivered as well as dissemination of results at various conferences.

Thesis:

Jonsson, P. (2010). *Sheet metal trimming dies – characterisation methods of geometry and surface topography and influence of wear (Licentiate thesis, Department of Materials and manufacturing Technology, Chalmers University of Technology, ISSN 1652-8891)*

Indirect through parallel interaction research projects OptiDies has contributed to the following Doctoral thesis;

Berglund, J. (2011). *Characterisation of Functional Pressing Die Surfaces. Doctoral thesis, Department of Materials and manufacturing Technology, Chalmers University of Technology, ISBN 978-91-7385-541-9.*

Journals:

Berglund J., D. Wiklund, B.-G. Rosén, *A Method for Visualization of Surface Texture Anisotropy in Different Scales of Observation*, Scanning, 2011, **33** (5) p. 325-331.

D. Wiklund, Magnus Liljengren, B.-G. Rosén, Kenneth Kjellsson, *Robust functional parameters of tool surface topography in sheet metal forming. Sent to Wear during August 2012.*

Conferences:

P. Jonsson, J. Berglund, K. Kjellsson, B-G. Rosén, *Surface Topography on trimming dies and the influence of wear.* Proceedings of IDDRG 2010 International Conference, pp. 639-650; 2010.

D. Wiklund, Liljengren M., Berglund J., Bay N., Kjellsson K., Rosén B-G., *Friction in sheet-metal forming - a comparison between milled and manually polished die surfaces.* Proceedings of the 4:th International Conference on Tribology in Manufacturing Processes, Nice, France, 13-15 June, 2010.

D. Wiklund, Larsson M., *A friction model for the boundary and mixed lubricated regimes in sheet metal forming.* Proceedings of the 15th Nordic Symposium on Tribology, NORDTRIB 2012, 12-15 June, Trondheim, Norway.

D. Wiklund, *Prediktering av friktion och slitage med hjälp av FE-simulering vid plåtformning,* Production cluster conference: Meetingplace for future succesfull workshops, Katrineholm, Sweden, May 24-26, 2011.

M. Liljengren, K. Kjellsson, *Rätt verktygsval ger kostnadsbesparingar.* Production cluster conference: Meetingplace for future succesfull workshops, Katrineholm, Sweden, May 24-26, 2011.

M. Kjellberg, M. Liljengren, *Frästa Funktionsytor.* Production cluster conference: Meetingplace for future succesfull workshops, Katrineholm, Sweden, May 22-24, 2012.

P. Hansson, M. Liljengren, *Use of Modern Tool Steel and Surface Engineering in Sheet Cold Forming*. Proceedings of the 9th International Tooling Conference, Tool 2012, Leoben, Austria, 11-14 of September, 2012.

Optimala verktygsytor för aktiva kallarbetsverktyg, (Poster presentation). Interaction meets the challenges of the vehicle industry, , FFI Sustainable production technics and transport efficiency, Älvsjö, Sweden, October, 2010.

Other distributing activities:

OptiDies has been presented in Plåtforums Medlemsblad at three occations: no 1 2010, no 2 och 2010, no 3 2011.

Internal Volvo Car Corporation (VCC) conference, Spreading of project results, February, 2011.

7. Conclusions and future research

Taking the tribo-system into consideration for forming and cutting tools has been a major challenge. Documentation of the industrial working die surfaces has been a very good start platform and has given the project important basic facts, one such fact has been that surfaces with high Ra value compared to surfaces with low Ra value may yield the same positive result. This is revolutionizing in the sense that the current level of approved Ra value in industry is very low, and to reach this level great effort is required.

For the forming tools the most influencing key factor is to divide the surface into three parts, peak, core and valley due to these have different tribo-functions. Use of parameters which don't have enough resolution, e.g. R_a (2D), simply don't give enough information to understand the actual tribo-system. Results from tests have shown that surfaces having relatively large cavities, which may originate from for example graphite nodules or polishing defects, can still deliver an approved component surface if the active die surface is controlled.

For the cutting tools the largest affecting factor has been the geometry of the cutting edge, cutting clearance and surface roughness of the clearance side. Proper selection of cutting clearance in combination with a start radius of the cutting edge has yielded the most reliable solution. The geometry of the cutting edge radius is less important than the cutting clearance regarding abrasive wear.

Pertaining to achieve qualitative results regarding the numerical economy model and to calculate the total cost the conclusive factor has been to include and integrate all cost driven parameters. The dominating parameter when it comes to the maintenance cost is hard to break out due to the fact that they are hidden in the overall cost and not specified. There is a potential for the industry to make improvements within the area of calculating the maintenance cost.

The results from OptidDies combine academic height (scientific journal articles and contributions to theses), with direct industrial application (new in-house standards and technical specifications). The work has also identified a number of exciting opportunities to future work areas for changing and improving the die manufacturing process to further reduce costs and increase of the performance of forming and cutting tools.

Examples of identified future work areas
The project has had many in-depth studies and analyses which have yielded further issues, opportunities and improvements, which in turn require further research. Improvement needs to cover small areas as well as greater overall processes. Some of these where there is a great opportunity to expand the understanding and competence are;

• The project showed possibilities to manufacture machined functional die surfaces, with no need of manual polishing. Thereby, improved machining strategies have a great potential to reduce the need of manual polished surfaces. The machining strategies developed in the project were time consuming with today's machines not cost competitive when compared with traditional machined and polished surfaces. Further development is required to produce such surfaces cost and time efficient in industry.

• *The method of using variable friction to predict the risk of wear showed good potential. Based on an implemented friction model the generated frictional energy is calculated using the FEM simulation software during a forming operation. The aim of the method is to create a better decision support for tool design through highlighting the areas which are highly stressed and may require more advanced materials, heat treatments, surface coatings etc. Some limitations in the use of the software would need to be resolved for future use and that more resources are allocated to develop and validate the method.*

• The surface quality of the formed part is traditionally considered to depend on the surface roughness of the die (low Ra value). Artificially made defects, with different characteristics, on a well-defined die surface have clearly shown that new defect sizes and distributions requirements have to be established when stamping EHSS sheet. To understand the influence of die surface defects on the surface quality of the formed parts

on other sheet grades, further research efforts are required. The study of approved defects has generated further possibilities to significantly decrease lead time in die manufacturing and costs.

The project group proposes an additional venture to further investigate the identified topics.

8. Participating parties and contact persons

Projectleader		
Volvo Cars Body Components AB	Kenneth Kjellsson	+46 454 264930
Övriga deltagare		
Scania CV AB	Lars Månsson	+46 491 765367
AB Volvo	Lars-Ove Gustavsson	+46 90 707362
Finnveden Metal Structures AB	Krister Svensson	+46 454 774750
Uddeholm Tooling AB	Nader Asnafi	+46 563 17051
IonBond Sweden AB	Greger Håkansson	+46 13 253301
Bodycote Värmebehandling AB	Mats Jogin	+46 13 253328
Duroc Tooling i Olofström AB now		
Lasertool i Blekinge AB	Jan Kvist	+46 454 48930
SSAB Strip Products AB	Lars Troive	+46 243 71797
SSAB Plate Division AB	Per Hansson	+46 155 254 632
Castolin Scandinavia	Hans Bengtsson	+46 31 570470
SKF Sverige AB	Christian Holmer	+46 31 3372967
Sandvik Tooling RTC D & M	Johan Berglund	+46 70 780 6050
Industriellt UtvecklingsCentrum	Magnus Liljengren	+46 454 97558
Swerea IVF AB	Elisabeth Sagström	+46 31 706 60 67
Högskolan i Halmstad	Bengt-Göran Rosen	+46 35 167604
** Camito AB*	*Göran Hjertstedt*	
** Saab Automobile AB*	*Henrik Pettersson*	

**Left the project due to bankruptcy of the companies.*

FORDONSSTRATEGISK
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Adress: FFI/VINNOVA, 101 58 STOCKHOLM
Besöksadress: VINNOVA, Mäster Samuelsgatan 56, 101 58 STOCKHOLM
Telefon: 08 - 473 30 00